DISCOVERY AND DISENTANGLING OF MULTI-MODE δ-SCT PULSATIONS IN THE ECLIPSING BINARY V994 HER

SERGIO DALLAPORTA[1] AND ULISSE MUNARI[2]

[1] Via Filzi 9, I-38034 Cembra (TN), Italy

[2] INF Osservatorio Astronomico di Padova, Sede di Asiago, I-36032 Asiago (VI), Italy

V994 Her (= HD 170314 = BD +24.3425, spectral type A0) has been discovered as a variable star by the Hipparcos satellite (HIP 90483, V_T=7$^{\rm m}$00, B_T=7$^{\rm m}$01, H_P=6$^{\rm m}$95) which recognized it as an eclipsing binary star with the following ephemeris giving times of primary minima:

$$\text{Min. I} = \text{HJD } 2448501.1239 \quad + \quad 2^{\rm d}\!.0830900 \times E \tag{1}$$
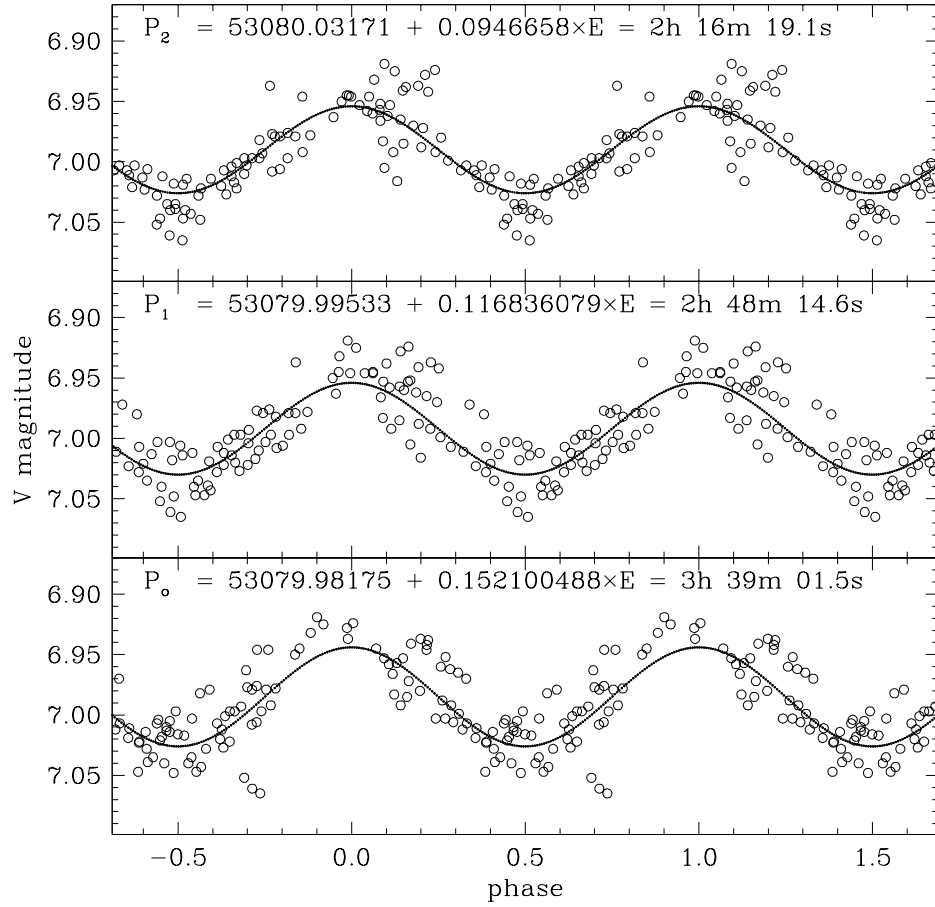
The brightness is H_P=6$^{\rm m}$93 outside eclipses and H_P=7$^{\rm m}$24 at primary minimum. V994 Her is located at α=18 27 45.89 and δ=+24 41 50.7 (J2000.0), corresponding to galactic coordinates l=52.94 and b=+15.90. The parallax measured by Hipparcos is $\pi = 4.14 \pm 1.16$, for a distance of $\sim$240 pc.

V994 Her is since long known as a close double. Among others, Abt (1985) gives for 1952 a P.A.=31.4 deg and a separation 1.93 arcsec, while Ling & Prieto (2000) provide for 1999 a P.A.=358.4 deg and a separation 1.20 arcsec. Hipparcos measurements for 1991 gives P.A.=0.7 deg and a separation 1.20 arcsec. From Tycho data, Fabricius & Makarov (2000) derived V_T=7$^{\rm m}$16, B_T=7$^{\rm m}$17 for the brighter component (=V994 Her itself, the eclipsing variable) of the astrometric pair, and V_T=9$^{\rm m}$00, B_T=9$^{\rm m}$24 for the fainter companion 1.2 arcsec away, which could be itself variable in brightness. Apart from these astrometric measurements and timing of some eclipses (Borkovits et al. 2002, 2004; Ak & Filiz 2003), not much else is known for V994 Her.

We observed V994 Tau in V band (standard Johnson filter) from a private observatory near Cembra (Trento), Italy, in a similar way to our previous investigations of V432 Aur (Siviero et al. 2004) or HD 23642 (Munari et al. 2004). The instrument was a 28 cm Schmidt-Cassegrain telescope equipped with an Optec SSP5 photometer. The diaphragm had a size of 74 arcsec, and the exposure time was usually 10 seconds. HD 168957 (HIP 89975, V_J=6$^{\rm m}$978, $(B - V)_J$=-0.095, spectrum B3V) was chosen as comparison star and HD 336061 (TYC 2097-687-1, V_J=8$^{\rm m}$58, $(B - V)_J$=+1$^{\rm m}$37, spectrum K5; as for HD 168957, Johnson's B_J, V_J are derived from Tycho's B_T, V_T values following Bessell 2000 transformations) as a check star. The comparison has been measured by Hipparcos 187 times and found constant. We have measured it against the check star 23 times in different nights and found V_J=8$^{\rm m}$58 with σ_V=0.01 mag, thus pretty well confirming the absence of variability.

$$\mathrm{P_{orb}} = 2452436.4213 + 2.0832179 \times \mathrm{E}$$
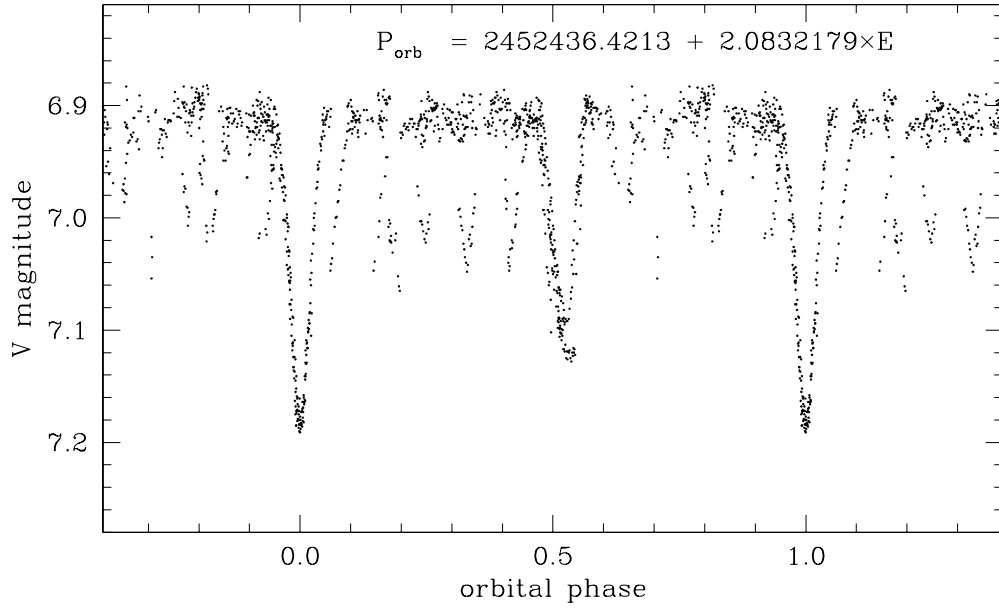
Figure 1. Our V-band photometry of V994 Her folded onto the orbital ephemeris given in Eq. (2)

$$\mathrm{P_2} = 53080.03171 + 0.0946658 \times \mathrm{E} = 2\mathrm{h}\ 16\mathrm{m}\ 19.1\mathrm{s}$$

$$\mathrm{P_1} = 53079.99533 + 0.116836079 \times \mathrm{E} = 2\mathrm{h}\ 48\mathrm{m}\ 14.6\mathrm{s}$$

$$\mathrm{P_o} = 53079.98175 + 0.152100488 \times \mathrm{E} = 3\mathrm{h}\ 39\mathrm{m}\ 01.5\mathrm{s}$$
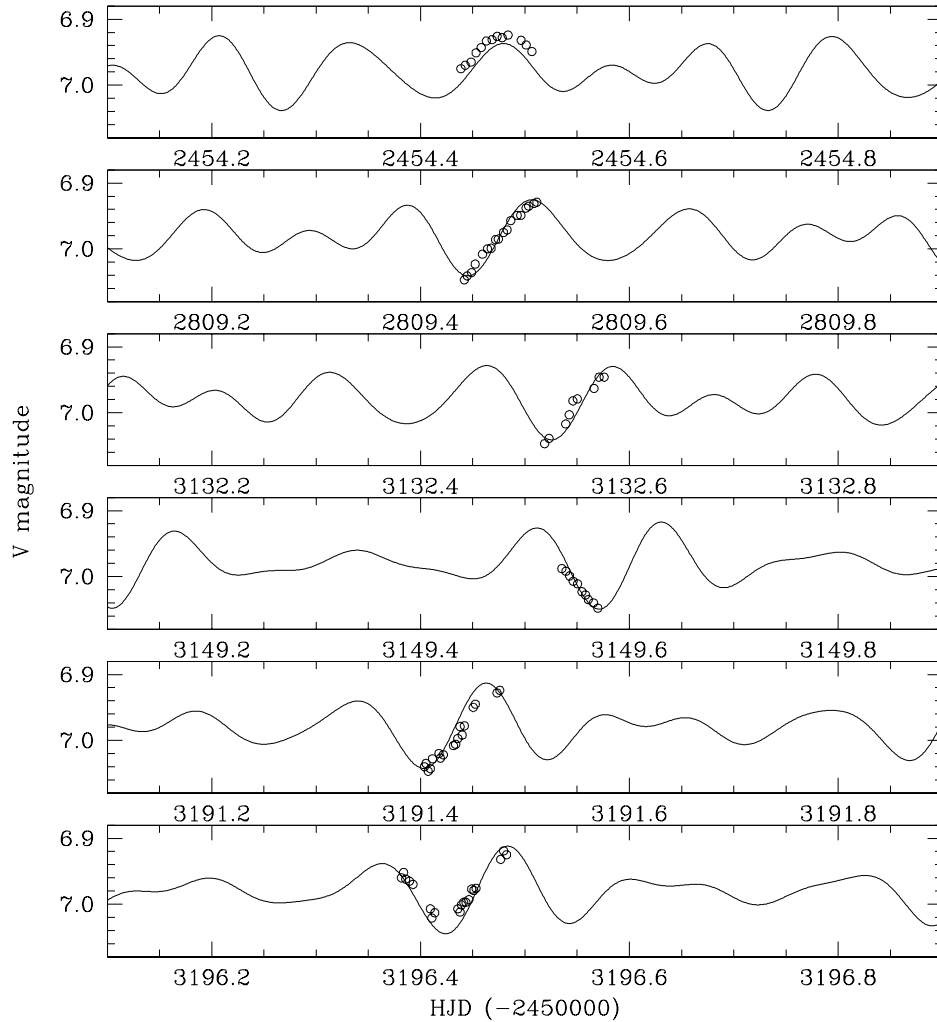
Figure 2. Our V-band data of V994 Her outside eclipses folded onto the three main periodicities (fundamental, I and II overtone) derived for the δ-Sct pulsation via Fourier analysis.

All together, we have collected 1170 measurements in V band of V994 Her between June 10, 2002 and July 15, 2004. All observations were corrected for atmospheric extinction and color equation (via calibration on Landolt's equatorial fields), and the instrumental differential magnitudes were transformed into the standard Johnson UBV system. The variable, comparison and check stars are close on the sky so the atmospheric corrections were rather small (108 arcmin distance for HD 168957 and 66 arcmin for HD 170650). The close similarity of the color between the variable and comparison star and the fact that all observations have been obtained for zenith distances $< 60°$ argue for a high internal consistency of our photometry of V994 Her.

A Deeming-Fourier code has been applied to the set of data, resulting in the following ephemeris for the orbital period of the eclipsing binary

$$\text{Min. I} = \text{HJD } 2452436.4213(\pm0.0003) \quad + \quad 2\overset{\text{d}}{.}083218(\pm0.000002) \times E \qquad (2)$$

Our V photometric data folded to this ephemeris are presented in Figure 1. Outside eclipses it is V=6.91 and at primary minimum V994 Her gets fainter by $\Delta V \sim 0.27$ mag. The secondary eclipse falls around orbital phase 0.52, indicating an eccentric orbit.

Figure 3. Sample segments of our V-band data of V994 Her away from eclipses compared with the multi-mode δ-Sct pulsation as given by Eq. (4).

However, the most attracting feature of the lightcurve in Figure 1 is the presence of a strong, short period variability in addition to the eclipse modulation. The amplitude of such variability is of the order of $\Delta V \sim 0.13$ mag, with a period of a few hours. This short period variability originates in the eclipsing binary, not in the nearby astrometric companion. In fact, Hipparcos lightcurve for the eclipsing binary alone show a similar 'scatter' of the data outside eclipses.

We have used a Deeming-Fourier code to search for periodicities in the photometric data of V994 Her outside the eclipses. Three firm periodicities ($0^{\rm d}.152100$, $0^{\rm d}.116836$, $0^{\rm d}.094666$) emerge from the analysis. The data outside eclipses are phase plotted against each of them in Figure 2. Their periods and amplitudes are reminiscent of δ Sct type of variability. It is worth noticing that their ratios are:

$$\frac{\mathrm{P}_1}{\mathrm{P}_{\mathrm o}} = 0.786 \qquad\qquad \frac{\mathrm{P}_2}{\mathrm{P}_1} = 0.810 \qquad\qquad (3)$$

which are very typical of δ Sct variables (e.g. Fitch 1976) and closely similar to those expected from theoretical modeling (e.g. Cox et al. 1979). We are therefore inclined to conclude that in V994 Her there is a δ Sct-like variable showing multi-mode pulsations, caused by the contemporaneous presence of fundamental ($P_o = 0^{\rm d}.152100$), first overtone ($P_1 = 0^{\rm d}.116836$) and second overtone ($P_2 = 0^{\rm d}.094666$) modes.

Our observations have been typically collected a few per night. However, in some occasions, longer sequences have been acquired. Those away from eclipse phases are plotted versus time in Figure 3, where the continuous line is the multi-mode pulsation described by the sine-wave equation:

$$
\begin{aligned}
V \;=\; 6.98 \;\; &+\; 0.031\sin\left[2\pi\left(\frac{t - 53079.9818}{0.152100488} - \frac{1}{4}\right)\right] \\
&+\; 0.025\sin\left[2\pi\left(\frac{t - 53079.9953}{0.116836079} - \frac{1}{4}\right)\right] \\
&+\; 0.015\sin\left[2\pi\left(\frac{t - 53080.0417}{0.09466580} - \frac{1}{4}\right)\right]
\end{aligned}
\qquad (4)
$$

that provides a good fit to the observed data, indicating the continous presence - with stable amplitude and phase - of these three modes of pulsation over the two years spanned by the observations in Figure 3.

References:

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